2° International Electronic Conference on Sensors and Applications

15-30 November 2015

POLITECNICO
DI MILANO

Assessment of polysilicon film properties through on-chip tests

Ramin Mirzazadeh, Aldo Ghisi and Stefano Mariani

Politecnico di Milano, Department of Civil and Environmental Engineering Piazza Leonardo da Vinci; E-Mails: ramin.mirzazadeh@polimi.it (R.M.); aldo.ghisi@polimi.it (A.G.); stefano.mariani@polimi.it (S.M.)

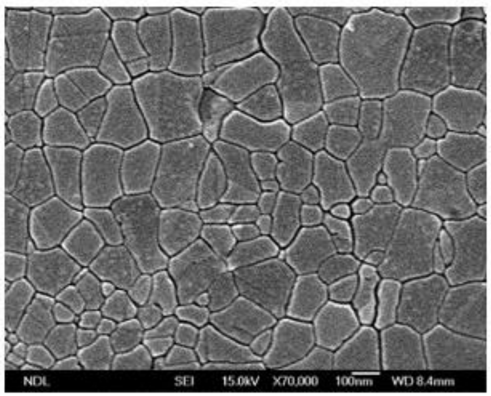
Research Aim

- Silicon the most common material used in Microelectromechanical Systems(MEMS)
- Anisotropic crystalline material whose material properties depends on orientation relative to the crystal lattice
- Characteristic length of mechanical components can be compared to the size of grains

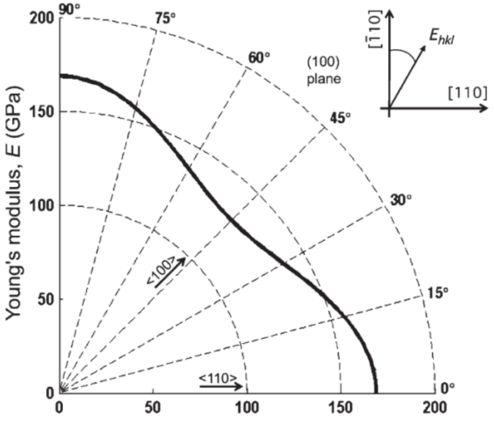
- Morphology & crystal lattice orientation are not known

Sources of uncertainties in mechanical response

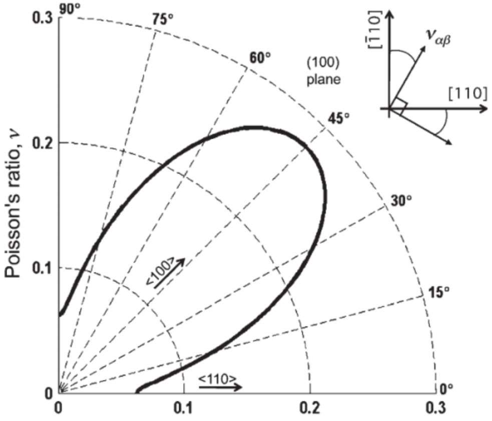
- These sources of uncertainties should to be addressed
  - Experimentally
  - Analytical and numerical modeling



http://www.ieo.nctu.edu.tw/leo/htms/photon/Laser%20Annealing.htm



Young's modulus of Silicon, (100) plane



Poisson's ratio of Silicon, (100) plane

Hopcroft,M.A.,et.al.,"What is the Young Modulus of Silicon?", *JMM*,2010

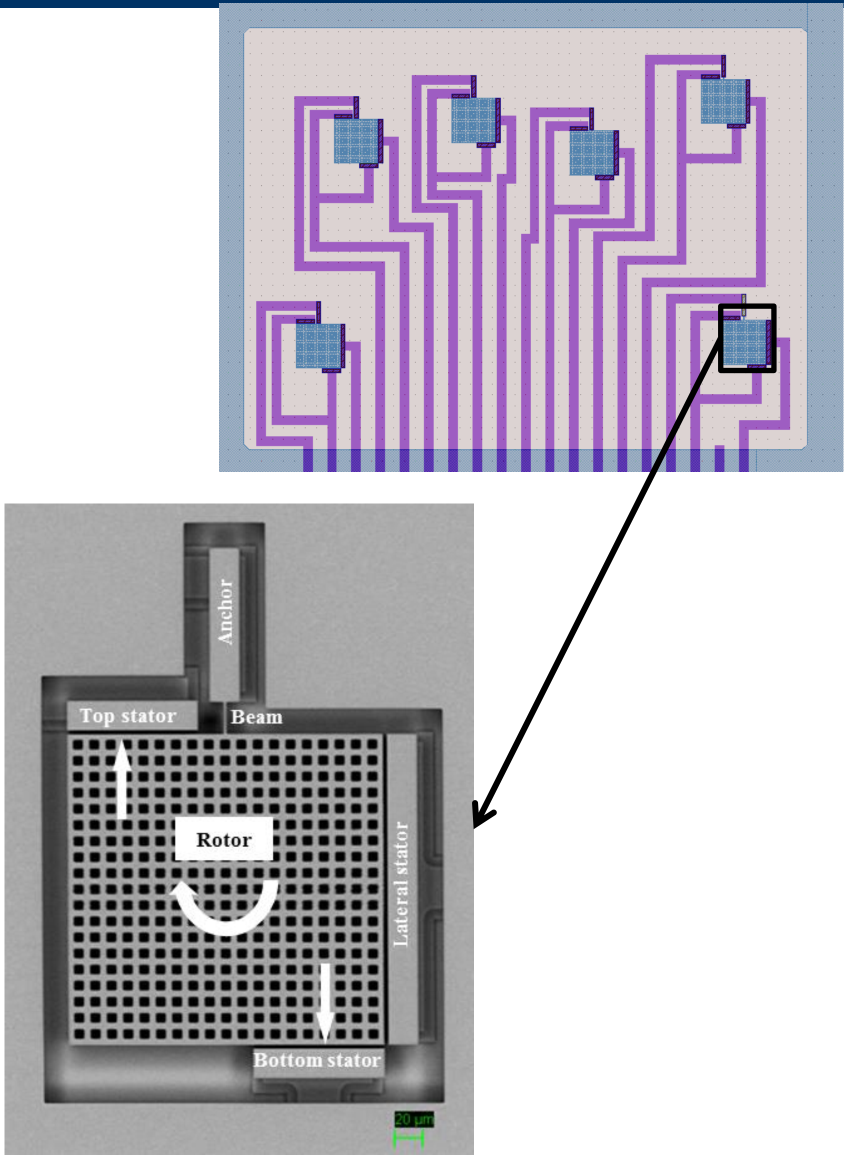
Designed Experiments

- An on-chip test adopted
- The specimen is a micro-beam made of polysilicon with average grain size of 500nm

- 6 devices featuring
  - Width: 2µm
  - Length: 2, 3 , 4, 5, 10, 20 µm

- Electrostatic actuation/sensing
- Two sets of conductors providing 4 combinations of sensing /actuation

- The electromechanical response varies between devices either due to
  - Geometrical uncertainties
  - Material uncertainties

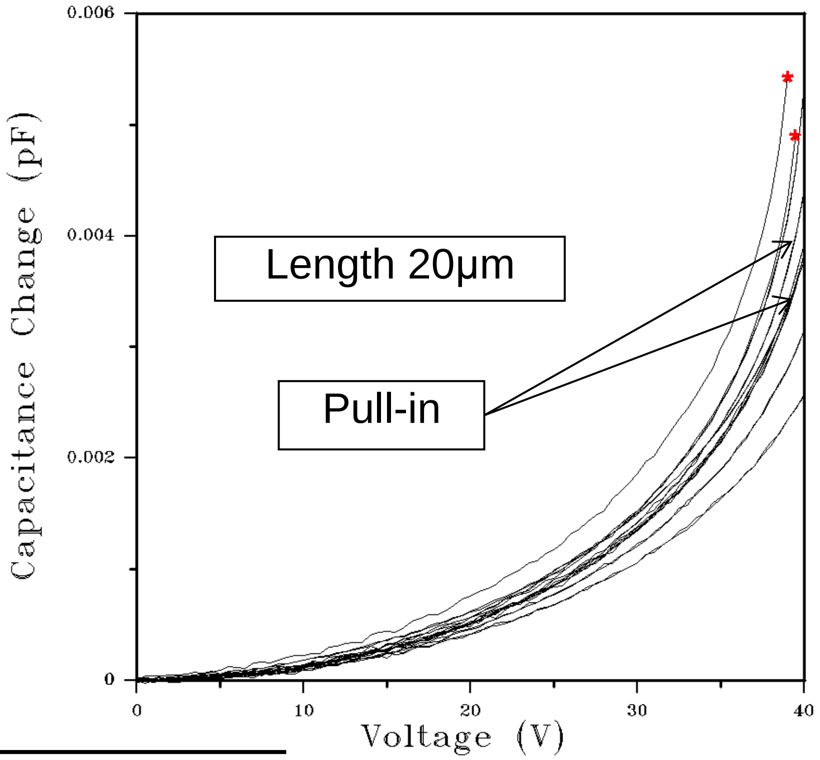


Experimental tests rotational mode

- The measurement is repetitive and reproducible except for the ones with pull-in

- The bias voltage difference is increased and then decreased to zero (max40V)

•Pull-in at 39.25-39.75



Length 20μm

Pull-in

Parameter	value	Parameter	value
beam length (l)	2, 3, 4, 5, 10, 20 μm	referenced initial gap between rotor and stators (g_o)	2 μm
beam thickness (h)	2 μm	a	17 μm
out-of-plane thickness (w)	22 μm	b	100 μm

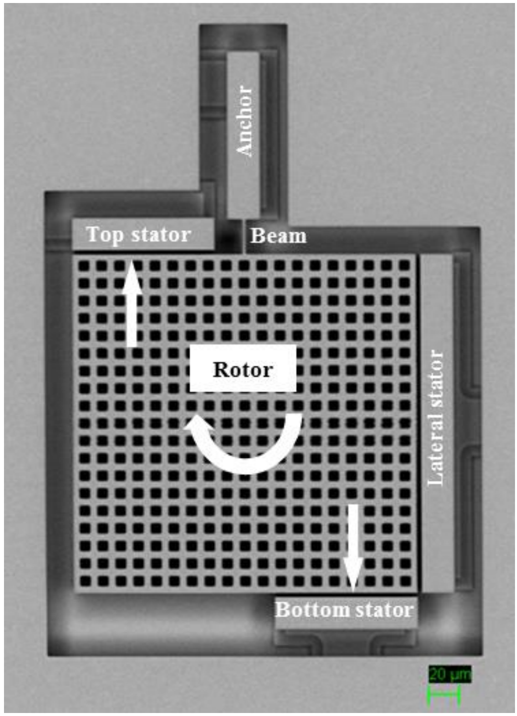
Analytical Model

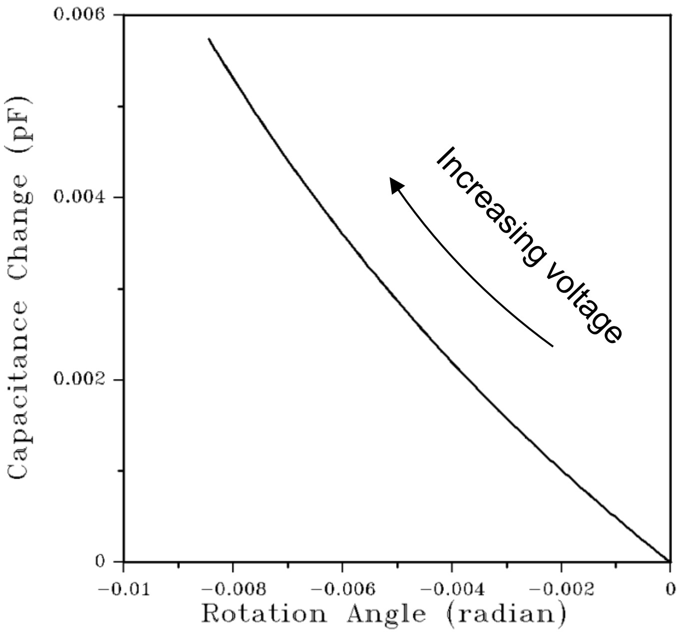
- Simplifications:
  - Big mass to be rigid
  - The micro-beam kinematics to be governed by Euler-Bernoulli
  - Electric fringe field neglected
  - No deformation at the anchor

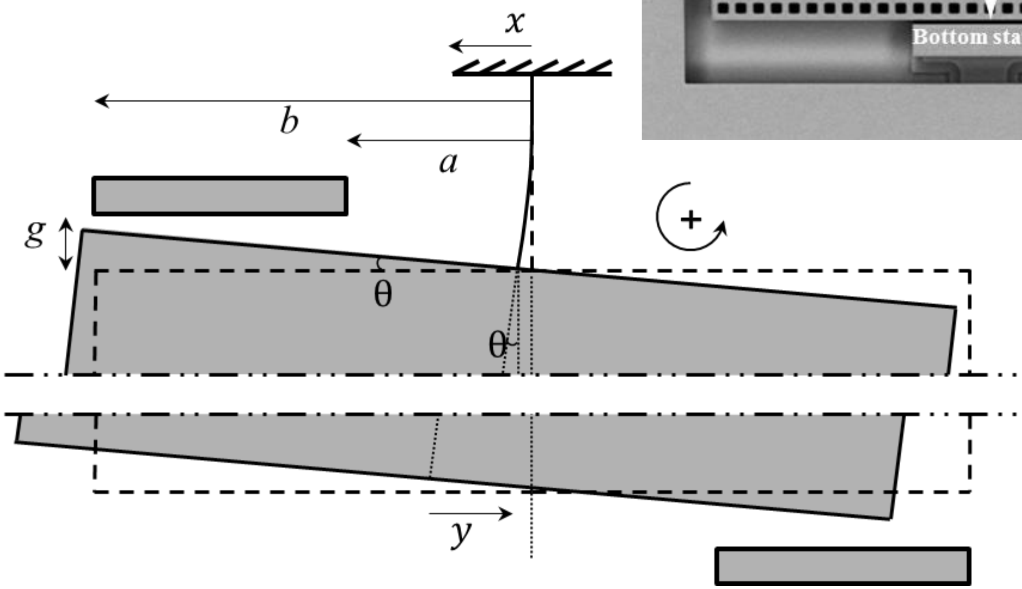
Closed form solution for Capacitance change as a function of voltage difference

Coulomb's law for parallel charged plates

$$F_{elec} = \frac{1}{2}\frac{\varepsilon_o A V^2}{gap^2}$$

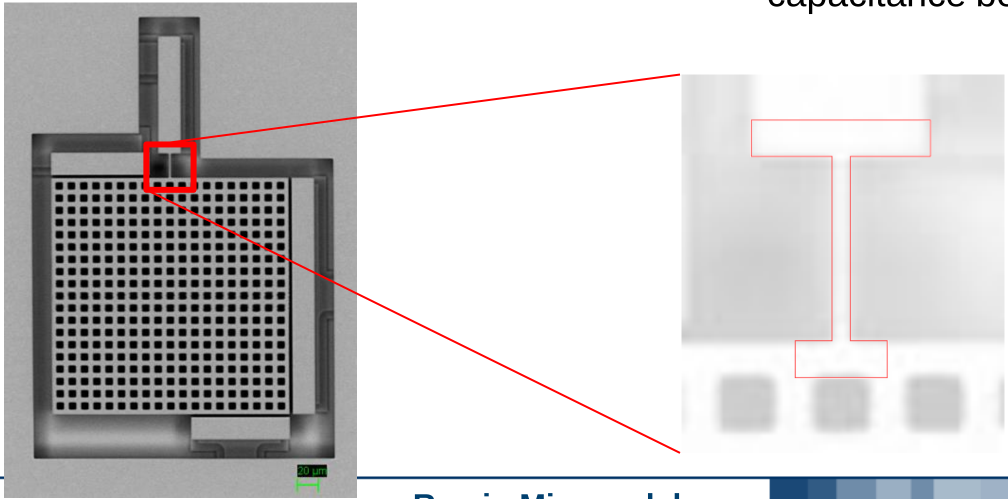






Numerical Modeling

- Simplifications:
  - Electric fringe field neglected
- Parametric geometry
  - Parametric study on overetch values
- Big mass is modelled by homogenized isotropic elastic properties
- Two scenarios for beam modeling
  - Homogeneous model
    - Bounds of response
  - Heterogeneous model



For each given $\boldsymbol{V}$

$$\boldsymbol{KU} = \boldsymbol{F}_{\boldsymbol{ext}} + \boldsymbol{F}_{\boldsymbol{elec}}(\boldsymbol{V}) \quad \rightarrow \text{Structural domain}$$

$$\boldsymbol{K}_{\boldsymbol{dielec}}\,(\boldsymbol{U})\boldsymbol{V} = \boldsymbol{Q}(\boldsymbol{U},\boldsymbol{V}) \quad \rightarrow \text{Electrostatic domain}$$

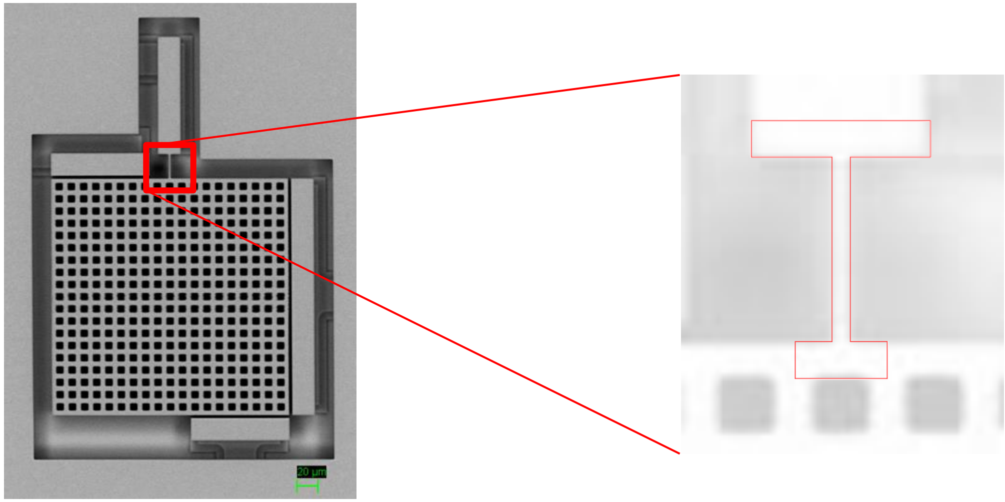
- Nonlinear coupled field analysis
  - Electrostatic forces on boundary nodes
  - Deformation effect the dielectric and electric field

$\boldsymbol{U}$ is used to update the geometry

- Electrostatic analysis for calculation of mutual capacitance between conductor systems

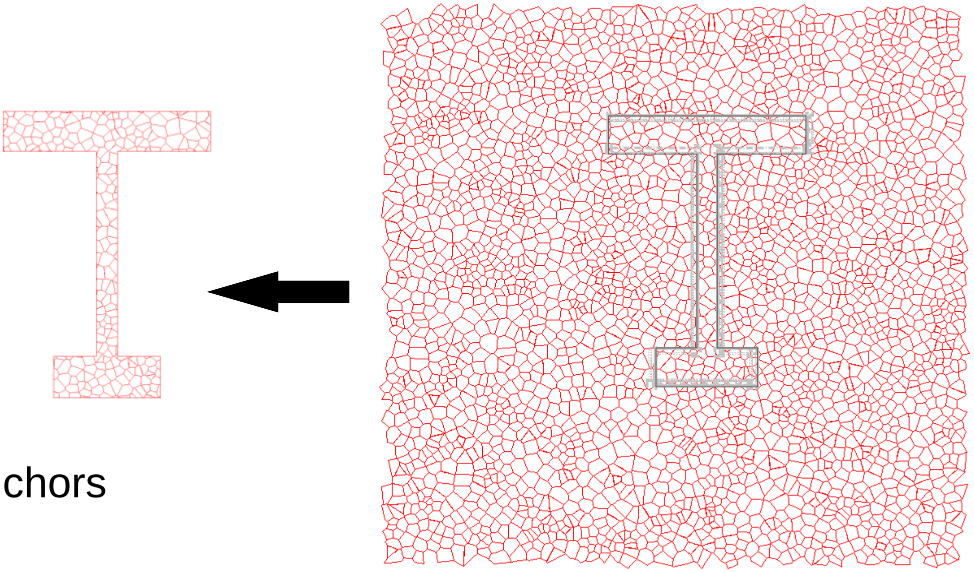
Numerical Modeling
Random Morphology

- Two scenarios for beam modeling
  - Homogeneous model
    - Bounds of response
  - Heterogeneous model
    - Monte Carlo simulation



- Voronoi diagram

- 100 times



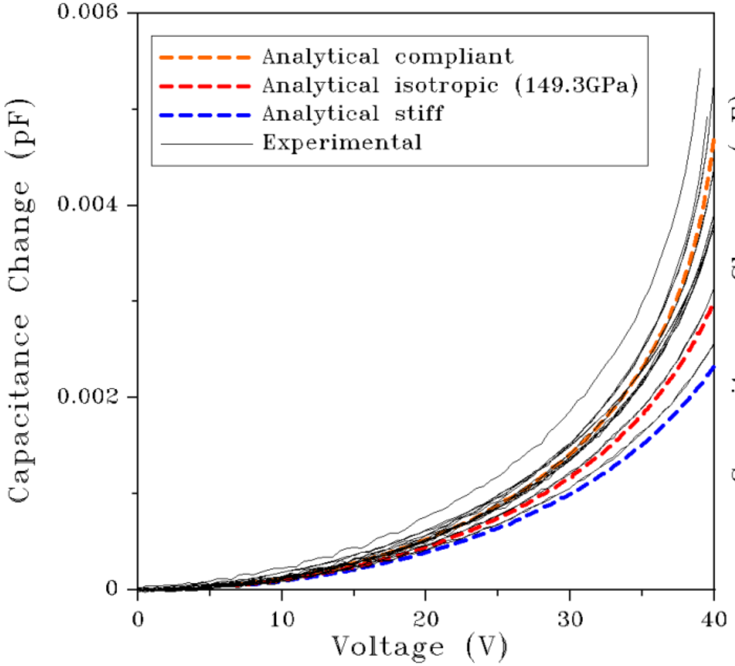
- Random mask position
- Random lattice orientation

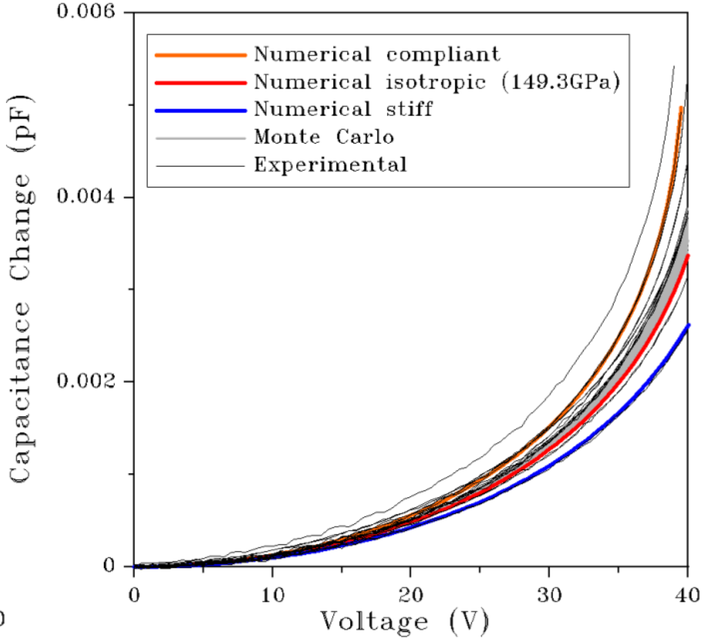
- Random morphology at beam and its anchors

Numerical and Analytical Model Results

- Three different values for crystalline orientation of silicon
  - Direction <110> E=169GPa (Stiff)
  - Direction <100> E=130GPa (Compliant)
  - Homogenized value E=149.3 GPa*
- Good bounds are provided for the experimental data

- Overetch can happen
  - Intensity depends on the geometry
- Geometry can vary slightly from device to device
- Overetch effect needs to be considered





*Mariani, S., et.al., Overall elastic properties of polysilicon films: a statistical investigation of the effects of polycrystal morphology. *Int J Multiscale Com,2011.*

Remarks

- Sources of material uncertainties in polysilicon film morphology is studied
- An on-chip test is designed to study the effect of morphology on the response of a micro beam
- The experimental results are modelled analytically and numerically
- Both models can bound the response scatterings
- The Monte Carlo simulation is carried out
- The effects of overetch at the response scattering should be studied

Acknowledgment

❖Financial support provided by STMicroelectronics through project MaRe (MAterail REliability) is gratefully acknowledged.

POLITECNICO
DI MILANO

Thank you for your kind attention!